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AGROFORESTRY AS A RESILIENT STRATEGY IN MITIGATING CLIMATE CHANGE IN MWANGA DISTRICT, KILIMANJARO, TANZANIA

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Abstract

Agroforestry is a climate-smart production system and considered more resilient than monocropping in mitigating climate change. Study was conducted to analyze the potential of agroforestry in mitigating CO_2 emissions through carbon sequestration in Mwanga district, Kilimanjaro, Tanzania. Methodologies used included literature review and ecological survey. A sample of 54 plots engaged in different agroforestry systems were randomly selected from three villages of different altitudinal range for colleting inventory and ecological data. SPSS computer program was used to analyze ecological data and allometric equations were used for estimation aboveground biomass and carbon. The diversity of agroforestry practices such as parklands, homegardens and woodlots stored a substantial aboveground carbon stock (10.7 to 57.1 Mg C ha^{-1} with an average of 19.4 Mg C ha^{-1}), and was statistically significant . Agroforestry showed a great potential in mitigating CO_2 than treeless systems therefore concerted effort should be made by different stakeholder in supporting agroforestry.

***Keyword**:* Carbon stock, Carbon substitution, Eco - efficient and Resilient.

1.0 Introduction

Global warming, the increase in temperature of the earth`s near surface air and ocean in recent decades, is believed to be brought about primarily by the increase in atmospheric concentrations of the so-called greenhouse gases (GHGs). Carbon dioxide is a major GHG, between 2000 and 2011; atmospheric concentration of CO_2 has increased from 369 to 391.5 ppm, a 6.1% of the eleven years (Conway and Tans 2012). According to its fourth assessment report, the Intergovernmental Panel on Climate Change (IPCC) emphasized that climate change is one of the most challenging problems presently facing humankind (IPCC 2007). Land use and land- use changes such as forest clearing, wetland encroachment and converting to agriculture and pasture, causes large carbon fluxes into the atmosphere and has been releasing 1.6-1.7Gt carbon annually (IPCC 2000).

Many Africa Countries including Tanzania are under pressure from climate stresses and is highly vulnerable to the impacts of climate change (Eriksen *et al*. 2007). Apart from poverty and lack of skills, overexploitation of natural resources, increased population and migrations, desertification and land degradation pose additional threats for example (Eriksen *et al*. 2007, 2008 and Rohit *et al*. 2006). While warming of global is now unquestionable; human being have been adapting to the variable climate around them for a centuries (Eriksen *et al*. 2008). According to Eriksen *et al*. 2008 and Rohit *et al*. 2006 exemplified that, future projection of the climatic changes and related effects on biological life will impact environmental norms and human population, causing serious negative disturbance to the global economy. Since, climate change impacts and responses are overlaid onto existing development processes and challenges. Therefore it is urgent that vulnerability to climate change of developing countries including Tanzania is reduced and enhance their ecological resilient or transforming lower carbon sinks (Adger *et al*. 2005; Eriksen *et al*. 2008; O`Brien 2011; Ulsrud *et al*. 2008), because large percentages of the populations of the developing countries like Tanzania depend upon rain-fed agriculture for their livelihoods.

In this paper, resilience is used in the context of climate change and variability, and for a system to be resilient, it must be able to continue to thrive and reproduce, and compete for space and resources in face of perturbation. According to FAO (2010);Hughes *et al*. (2005); Lin, (2011) and Thomas *et al*. (2011), resilience refer to the ability of a system to maintain key functions and processes in the face of stresses or pressures by either resisting, adapting or mitigating change, key functions includes: production (soil and nutrient management), ecological services (carbon sequestration).

Therefore complementally and robust strategies are required to enlarge the sinks of Carbon dioxide which is major GHGs (Yadava 2010 ;Eriksen *et al*. 2008, 2011 ;Berrang-Ford *et al*. 2011 and IPCC 2007). Through promoting C mitigation techniques and socio-ecological resilient that provide social, environmental, and economic benefits while reducing concentration of CO_2 in the atmosphere ; by either altering the way energy is used (carbon substitution) or increasing the rate of removal of the atmospheric CO_2 through sequestration and conservation of terrestrial carbon (Lin 2011; Montagnini and Nair 2004). Carbon sequestration is one of the many valuable environmental services that agroforestry system (AFS) provides in developing countries. Is the process of removing CO_2 from the atmosphere during photosynthesis and transfer of fixed C into long-lived pools (vegetation, detritus and soil pools) for secure storage whereas one ton of carbon being equal to 3.67 tons of CO_2 (Nair 2011 and Rohit *et al*. 2006).

Agroforestry (AF), as a tree based systems that combines trees and/or shrubs (perennial), animals and agronomic crops (annual crops) provides a particular example of a set of innovation that are designed to enhance REDD+ through carbon substitution, carbon conservation and carbon sequestration in agricultural landscape (Angelsen *et al*. 2012; Verchot *et al*. 2007; Nair 2009; Albrecht and Kandji 2003; Pandey 2007; Singh and Pandey 2011).

Despite the availability of overwhelming potential of AF in supporting climate change mitigation in Mwanga District in Tanzania, uncertainty prevails over the exact potential of AF in mitigating climate change especially at local level, complex systems and different altitudinal range making it difficult to plan and develop appropriate adaptation and transformation strategies (Charles *et al.* 2013; Nair 2011; Scheridan 2009; Verchot *et al.* 2007;Adger and Vincent 2005).

Thus, quantification of carbon pools in AF is necessary (Oke and Olatiilu 2011) for understanding the contribution and their potential carbon storage and C sequestration in Mwanga District, Tanzania. So that appropriate AFS could be developed to maximize C sequestration and carbon pools which are targeted by REDD+ initiative. In this context, this study aimed at assessing and analyzing the role of tree component of (AFS) in mitigation CO_2 emission.

2.0 Material and Methods

2.1 Study Site

The study was conducted in Mwanga district, (3°25′-3°55′S and 37°25′-37°58′ E). The district covers an area of 2641 km^2. Land area is 2,558.6 km^2 and water cover an area of 82.4 km^2 of Nyumba ya Mungu Dam and Lake Jipe. It characterized by semi-arid (lowlands) in the east and west that lie between 550-700 meters above sea level, it is particularly dominated by pastoralist and simple agroforestry systems or Parklands. The highlands have an altitude that range from 700-2500 meters above sea level, it is particularly known for coffee production and complex AFS such as homegardens and woodlots. It experience 400-600 mm of rainfall per annum in the lowland and between 800-1250 mm in the highlands. There are two distinctive rain seasons, short rainfall from October-December and Long rainfall from March-June. The highlands enjoy both the short and long rain seasons. The district experiences some strong and dry winds blowing normally from the East to the West. Temperatures range between an average of 14°c during June-July and 32°c usually in January. Land is covered by shrubs of acacia in both eastern and western lowland and forest around the Eastern arc mountain in the highlands. The surveys were conducted from December 2011 to February 2012. Rain-fed agriculture and livestock production are the main socio-economic activities practiced in highlands and lowlands, whilst lowland or semi-arid areas depend entirely on irrigation systems.

2.2 Sampling

The District was stratified based on administrative areas (see Figure 1). Three villages were selected purposively based on altitudinal range (Low altitude, medium altitude and high altitude) characterized by semi-arid, semi-humid and humid climatic conditions respectively. Fifty four agroforestry farm plots were selected randomly to cover as much as variation in tree species diversity as possible. At least five sample plots were established in each agroforestry systems. A rectangular plot with a plot size of 0.04 ha for Eucalyptus woodlots and 0.125ha (10 m ×125 m) or 1 ha for homegarden and parkland systems was adopted, in order to collect ecological information such as tree diameter, tree species composition, dominance and stocking. Whenever a plot size was small than one hectare, the whole plot were considered to be as sample plot. One sample plot was established in each selected agroforestry field. Inventory data collection form was used to capture field information such as tree diameter at breast height (DBH ≥5cm) in each plot (MackDicken 1997). In total, 777 individual tree measurements were established from 54 agroforestry sample plots.

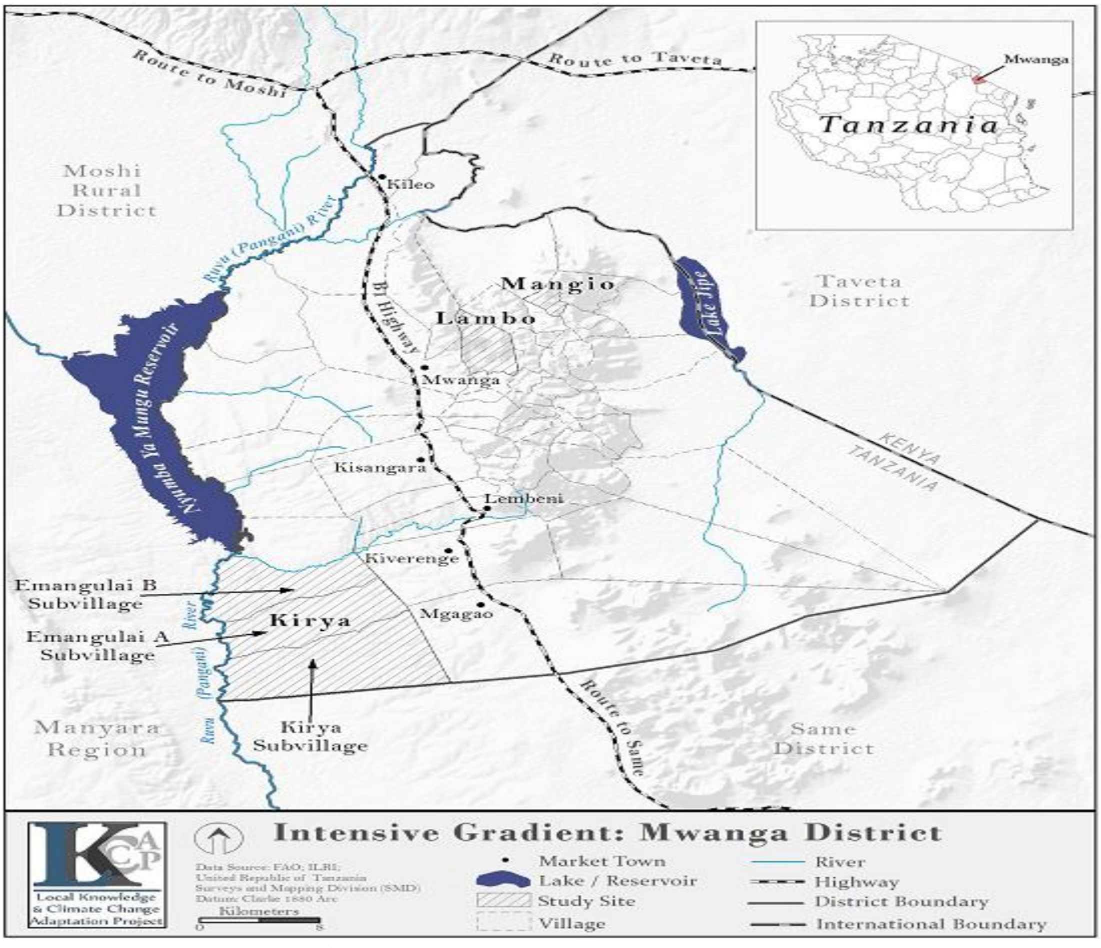

Figure 1: Map of Mwanga District, Kilimanjaro (Source: LKCCAP, 2012)

2.3 Biomass Estimation

All trees with DBH ≥5cm in each plot were measured for stem diameter and converted to aboveground biomass (AGB) using general allometric equations developed based on climatic conditions (Brown 1997) and the result expresses as tons (Mg) per hectare. Belowground biomass (root) was estimated by multiplying ABG by 0.3.Total biomass (TB) were estimated as sum of AGB and belowground biomass. Total carbon was estimated assuming that the carbon content of TB is 50% (MacDicken 1997), and summed by plot. Results were then scaled from Mg C plot^{-1} to Mg C ha^{-1}. The use of this general equations rather species specific equations was deemed acceptable for the purpose of this study, since reliable allometric equations for most of the species do not currently exist and the objective was merely to estimate the likely biomass storage and carbon sequestration where (1 C= 3.67 CO_2). One way Analysis of variance (ANOVA) were used to test the quality of three means, where the tests indicated significant difference among land-use type, means were contrasted with post hoc Scheffe tests. Basal area (BA) was used to determine stand characteristics or Stand Density: Quantitative measure of the degree of stem crowding in a stand, were expressed in terms of basal area per unit area. The following formula was used to calculate basal area; ($BA = \pi \times DBH^2/4$).

Allometric equation used

Dry (<900mm) $Y = \exp\{-1.996 + 2.32 \ln(D)\}$ $R^2 = 0.89$ (Eq.1)

Moist (1500-4000mm $Y = \exp\{-2.134 + 2.530 \ln(D)\}$ $R^2 = 0.97$ (Eq.2)

Where: Y = Aboveground biomass (Kg) and D = diameter at breast height (1.3 m).

3.0 Results

3.1 Potential of tree component of agroforestry in mitigating carbon dioxide emissions

The study revealed the variation in carbon stock among AFS from different altitudinal range. Result from survey revealed that, carbon stock of AFS ranged from 10.7 to 57.1 Mg C ha^{-1} (see Figure 2).

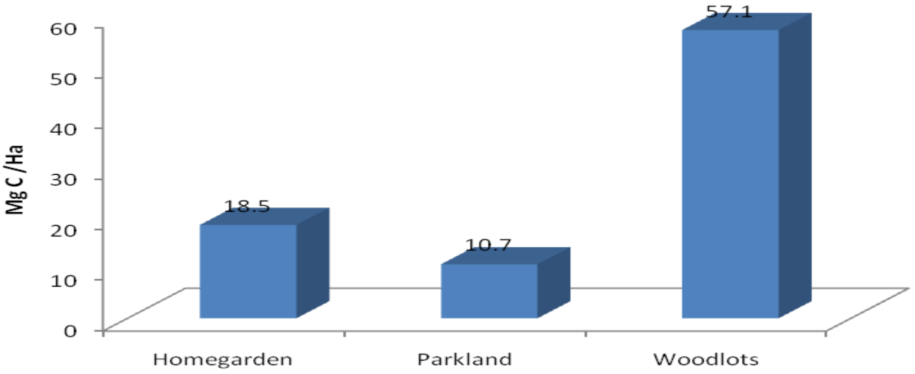

Figure 2: Comparison of carbon stocks (Mg C ha^{-1}) for different agroforestry practices

In general average carbon stock of AFS ranged from 5.3 to 45 Mg C ha^{-1}, while above ground carbon stock increased from parklands to homegardens to woodlots (F=131;P< 0.0001) see Table 1& 2.

Table 1: Comparison carbon stock of different Agroforestry practices

		Carbon stock (Mg C ha-1)			
Agroforestry practices	**N**	**Minim**	**Max**	**Mean**	**St.Deviation**
Woodlots	5	36.8	57.1	45	7.8
Homegardens	35	1.6	18.5	7.7	4.9
Parklands /Simple AFS	15	3	10.7	5.3	2.1

Table 2: Post hoc means comparisons of significant differences in carbon stock among agroforestry system (F=131; p<0.0001) (W= woodlot; H= Homegarden; P= Parklands).

Carbon stock Mg C/Ha			
Agroforestry systems	**Means differences**	**Std. error**	**Scheffe`s post hoc**
Woodlots Vs Homegardens	37.1	2.4	W > H > P
Woodlots Vs Parklands	39.7	2.5	W > H > P
Homegardens Vs Parklands	2.6	1.5	W > H > P

Parklands are defined or understood as landscapes in which mature trees occur scattered in cultivated or recently fallowed field. Carbon stock of the AFS showed high variation (Table 2). Management practices, tree density, species diversity and socio-economic factors were among the factors observed to increase carbon stock variation among AFS. For example, farmers observed to grow crops around and underneath of the trees selectively left or regenerated by farmers because of the variety of functions (mostly non-timber). Parklands were observed to be characterized by the dominance of one or few tree species. Common species are *Accacia species*, *Balanites aegyptiaca*, *Faidherbia albida*, *Salvadora persca*, *Azadirachta indica* , *Tamarindus indica* and *Kigeria africana*. High density of *Eucalyptus species* were revealed in woodlots both in the highlands and the medium altitude.

Homegardens revealed to have high density of Coffee in the highland compared to the medium altitude. Tree species composition in homegardens and land size were among the factors contributed to carbon dynamics. This was exemplified by higher tree richness in high altitude, followed by medium altitude. Similarly, tree dominance varied from highland to medium altitude for example *Mangifera indica*, *Cordia africana* and *Grevellia robusta* were dominance in medium altitude and *Coffee arabica*, *Grevellia robusta*, *Cordia africana* and *Persea americana* in the highlands homegarden. Other parameter like basal area per hectare of homegardens in altitudinal range also showed higher variation, and the main reason were observed to be contributed by socio-economic and environmental factors which motivated farmers to retain or plant trees on farms.

Field study also observed the contributions of multipurpose tree to carbon storage Table 3. Fruits tree such as Mango (*Mangifera indica*), Avocado (*Persea americana*) and Jackfruits (*Artocarpus heterophyllus*) were all top ranked C-stores; these species stored an average of 40.4% of the C stored in agroforestry. Such high multiple livelihood benefits exemplified the significance and potential of this trees species if used in reforestation projects for C storage. Field survey identified 40 different tree species grown /planted in AFS in Mwanga district (Table 3).

Table 3: Trees species abundance sampled in the 54 agroforestry farm.

Species name	Frequency	Percentage
Grevellia robusta	79	10.2
Cordia Africana	72	9.3
Tamarindus indica	11	1.4
Syzigium cordatum	8	1
Balanites aegyptiaca	3	0.4
Markamia obtusifolia	17	2.2
Croton Macrostachyus	5	0.5
Kigeria Africana	9	1.2
Eucalyptus saligna	124	15.9
Acacia tortilis	7	0.9
Salvadora persea	13	1.7
Cordia sinensis	2	0.3
Ficus thonningii	4	0.5
Albizia schemperana	8	1
Faidherbia albida	49	6.3
Commiphora eminii	11	1.4
Artocarpus heterophyllus	46	6
Persea americana	36	4.6
Mangifera indica	123	15.8
Anona muricata	16	2.1
Anona squamosa	11	1.4
Croton megarocarpus	3	0.4
Syzigium guineense	8	1
Azadirachta indica	12	1.6
Psidium guajava	3	0.4
Cocos nucifera	2	0.3
Cinamomam zeylanicum	1	0.1
Acrocarpus fraxinifolius	8	1
Rauvolfia caffra	1	0.1
Eucalyptus globules	1	0.1
Coffee Arabica	60	7.7
Pinus Species	3	0.4
Citrus species	1	0.1
Cedrella odorata	2	0.3
Acacia polyacantha	7	0.9
Albizia gummifera	8	1
Milicia excels	1	0.1
Borassus aethiopum	1	0.1
Ficus sycomorus	2	0.3
Carica papaya	1	0.1

For example, *Eucalyptus saligna* was top ranked species in our sites in term of carbon storage; others species observed were *Mangifera indica*, *Grevellia robusta*, *Cordia africana* and *Coffee arabica*. These tree species apart from being a sink for CO_2 through the process of photosynthesis, which accumulate C in tree biomass they also acted as socio-economic importance in the study area.

4.0 Discussion

4.1 Role of Trees on Farm in Mitigating Carbon Dioxide Emissions

Agroforestry, an ecologically and environmentally sustainable land use, offers great promise towards mitigating the rising atmospheric CO_2 levels through C sequestration (Nair, 2011). Tree crop sequestered C at a higher rate than those containing only in annual crops or grasslands (Brakas and Aune, 2011). Since annual crops will only accumulate carbon through roots and retention of crops residue, whereas tree crops will accumulate carbon through, roots, litter and above-ground biomass (Nair *et al*., 2009; Singh and Pandey, 2011; Jose, 2009).

Our field study revealed a great variation in AF practices, with more trees density in woodlots and higher diversity in other categories as discussed earlier. For example, parklands have an average carbon stock of 5.3 Mg C ha^{-1}, homegardens have an average of 8 Mg C ha^{-1}, and that of woodlots was 45 Mg C ha^{-1}. Carbon stock reported above were higher than that of (18-25 Mg C ha^{-1}) under 5 year–old rotation woodlots in semi –arid Morogoro, Tanzania (Kimaro *et al*., 2011), Australia (6.25 - 52.91 Mg C ha^{-1}: Walsh *et al*., 2008) and (4.9 Mg C ha^{-1}: Udawatta and Jose 2011) for temperate AF. Agroforestry C stock in Mwanga district are comparable with that of tropical agroforestry (13.7-54.6 Mg C ha^{-1}: Yadava 2010), (50-75 Mg C ha^{-1}: Verchot *et al*., 2007), (9, 18, 40 Mg C ha^{-1}: Montagnini and Nair 2004), (7.9 - 105 Mg C ha^{-1}: Roshetko *et al*., 2002). Similarly, C sequestration in the study area are within the range of (12-228 Mg C ha^{-1}) as reported by (Albrecht and Kandji 2003) for tropical agroforestry.

Indeed, a variation in Carbon estimate described above seems to be explained by the higher density and diversity of trees species (Example; Roshetko *et al*., 2002). Several studies revealed that, C storage in plant biomass is only feasible in perennial AFS with a mixture of fast-growing and slow-growing species, sprouting tree species and multipurpose trees. Since allow full tree growth (e.g. fruits tree) and where the woody component represents an important part of the total biomass (Albrecht and Kandji 2003; Kumar 2011; Nair *et al*., 2009). Thus, intensifying coppicing and multipurpose trees in AFS whereas carbon sequestration does not end at the wood harvest is necessary since will augment forest integrity. As described earlier, *Eucalyptus species* ranked higher among the dominance species. Apart from socio-economic benefits contained, *Eucalyptus species* reported to do an excellent job of sequestering CO_2 because they efficiently stored carbon in all their live biomass. It's sprouting and fast growth; Eucalyptus woodlots were reported to be more efficient than even native forests in term of carbon sequestration by offsetting carbon that is lost from harvesting of tree (Moges, 2010).

Our field observations confirmed that landowners added trees to AFS through time (Charles *et al.*2013). As results, C that is lost from senescing trees will be compensated by individuals that are planted in anticipation of the older trees` senescing. In this regards AFS seems attractive since there is no complete removal of biomass from the homegardens, signifying the permanence of these systems compared to plantation forest (e.g. Charles *et al.*2013; Kumar 2011 and Sileshi *et al*., 2007). But, our average carbon stocks were slightly lower than that of (16 to 36 Mg C ha^{-1}: Kumar 2011) for the tropical homegarden practiced in Kerala and carbon stock of (37.30 - 80.05 Mg C ha^{-1}: Wardah *et al*., 2011) for the AF practiced at adjacent Buffer zone of Lore Lindu National Park in Central Sulaweshi, Indonesia. Similarly higher estimate of (33.94 - 96.01 Mg C ha^{-1}) were reported from Cocoa based AF practiced in Ogbese Forest reserve Ekiti State, Nigeria (Oke and Olatiilu, 2011) and estimate of 93 Mg C ha^{-1} from small scale carbon sink project in eastern in Panama (Kirby and Potvin, 2007).

Our studies and several other literatures exemplify the contributions of farm size, management, socio-economic need, species diversity, age of tree, local climate and tree stocking/ spacing for carbon variability among AFS (Barnett and Adger, 2007; Kumar, 2011). However, carbon variation described earlier can be attributed to relatively age variation of the trees, higher level of disturbance (pruning and damage), intensive management practices and small land size that forced agroforestry practitioners not only having higher density of wood but also accumulation of other plant crops per unit area (Richard *et al*. 2013; Kumar, 2011; Oke and Olatiilu, 2011; Yadava 2010).

The aforementioned studies indicated that tree based systems are important sources of carbon sink which are targeted by REDD+ (Angelsen *et al*., 2012), even if variations of carbon stock in AFS as described above depended upon several factors (Albrecht and Kandji, 2003; Brakas and Aune, 2011; Nair, 2008; Nair, 2011; Singh and Pandey, 2011). For example trees species abundance in the study area varied from highland to lowland, *Mangifera indica*, *Cordia africana* and *Grevellia robusta* were dominance in medium altitude. While in highlands *Eucalyptus saligna* ranked the top, others were *Coffee arabica*, *Grevellia robusta*, *Cordia africana* and *Persea americana*. In Lowlands (semi-arid) *Faitherbia albida* ranked higher, others were *Salvadora persca*, *Azadirachta indica* , *Tamarindus indica* and *Kigeria africana.* Multipurpose tree species such as Mango (*Mangifera indica*), Avocado (*Persea americana*), Jackfruits (*Artocarpus heterophyllus*), *Faidherbia albida* and *Albizia species* were all top ranked C-stores; fruits species stored an average of 40.4% of the C stored in AF.

Similarly, Brakas and Aune (2011) reported higher carbon accumulation rate from agroforestry with high diversity. Biodiversity enhancement by AFS facilitated a better nutrient use and therefore increases C sequestration compared with tree-less AFS (Nair *et al*., 2009; Howlett *et al*., 2011; Singh and Pandey, 2011). However, having a large carbon stock does not necessarily mean having a large C sequestration. Since tree C sequestration also depends on very stable (long-standing) AFS and tree species like *Faidherbia albida* (`reversed leaf phenology`). For example, evergreen trees like *Persea americana*, *Syzigium species* and *Albizia species* retained C in the leaves for longer period of time than deciduous tree species, which cause regular inputs of organic matter into the soil, apart from the roots and its litter fall which is usually low until canopy closure (Ajayi *et al*., 2011and Mosquera-Losada *et al*., 2011). Udawatta and Jose (2011) reported individual tree in silvopastoral system to grew faster than in conventional forest on the same site, allowing silvopastoral trees to store more C.

While C sequestration in the study area for itself may be insignificant in mitigating CO_2, producing fuel wood from arable or grazed land may still present interesting opportunities in implementing REDD+ through: (1) the protection of existing forests, protected area and other natural landscapes; (2) the conservation of soil productivity; (3) extent income increased in agroforestry farmers reduces the incentive for further from natural forest and protected area for income escalation , and finally (4) reduce *leakage* by supplying wood and non-wood products (Albrecht and Kandji 2003; Angelsen *et al*. 2012; Montagnini and Nair 2004), it also substitutes the more energy-intensive construction materials like concrete, steel, gypsum board, fossil fuels, plastic and aluminium (Nair 2008; Singh and Pandey 2011).

According to Sileshi *et al.* (2007) agroforestry has a potential to offset 5-360 t ha^{-1} of GHGs through energy substitutions, up to 100 t ha^{-1} through materials substitution, and 1-5 t ha^{-1} through reductions of fertilizer inputs by increasing eco-efficient. Despite the potential of AFS in substituting inputs of synthetic fertilizer and pesticides with bio-pesticides and bio-manure (Charles *et al*. 2013; Adekunle and Aderogba 2008; Adekunle and Akinlua 2007; Smith 2010; Ulsrud *et al.* 2008), integrating multiple-use species such as trees for fodder and trees for land reclamation (phytoremediation) can substitute relatively energy intensive (Kumar 2006; Singh and Pandey 2011).

5.0 Conclusion

This study described the great potential of tree component of AFS in increasing C sequestration compare with tree-less agricultural systems, and therefore its implementation should be considered as a climate smart land use option in Mwanga district. However, our estimate clearly indicates possible gains in C stocks that could be used to promote agroforestry as a promising CO_2 mitigations strategy in Tanzania. Considering the high dependency on wood and non wood supply and soil improvement, AFS holds promise to minimize land degradation and deforestation which are targeted by REDD+ initiatives through supply of wood and non-wood products. Our studies and other studies undertaken so far at various locations and systems in tropical have shown that the factors that contribute to the C dynamics under AFS includes poor institution arrangement, greater diversity in vegetation (trees and crops), tree density, local climate, management in place, disturbance or damage, increased litter fall inputs to the soil and tree species phenology. Our results suggest that practices and research priorities should consider extending agroforestry species that match farmer preference and include those options that have direct potential for increasing farmer`s resilience to climate change.

Therefore, comprehensive and interdisciplinary strategies are needed in understanding how to deliberately transform AFS and society in order to avoid the long-term consequences of environmental change.

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